E/CONF.39/A/224
31 Oct.1962
ORIGINAL : ENGLISH

UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A.3.3

India

INVESTIGATION AND EXPLOITATION OF GROUNDWATER RESOURCES

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by

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INTRODUCTION

1. India is predominantly an agricultural country and for the growth, development and expansion of its rural economy which forms the backbone of her prosperity, nothing is more essential than water for irrigation. Although blessed with a network of rivers - big and small with a collosal annual run-off of the order of 1,672,600 million Cu. m. (1,356 million acre feet), there are vast tracts of cultivable lands which starve for want of any irrigational facilities. The bulk of this enormous run-off comes from precipitation in the four months of the monsoon season which mostly runs to waste, causing serious damages on its way to the sea by heavy flooding. Water in these rivers therefore, is not always available when required for irrigation and to hold it up in big storage reservoirs is a very expensive proposition. Moreover suitable sites for such reservoirs are few and far between. There are also arid zones to consider, like Rajasthan and southern Punjab where water is in perpetual scarcity. Even in heavy rain fall areas, a bad monsoon can spell disaster. All these considerations together with the progressively increasing demands for the use of water for industrialisation and urban needs, has led Engineers to devise ways and means for exploring groundwater supplies on a larger scale than has been attempted in the past. More homes today are equipped with water consuming devices and the per-capita consumption of water has risen very much higher than the old class book standards of a decade ago. This has further stimulated search for groundwater supplies to supplement surface water resources, both for rural and urban needs. The alarming rate of increase in population in underdeveloped countries is yet another important factor to contend with.

2. Use of groundwater has been as old as time itself and springs and shallow dug wells have been known from times immemorial. The science of groundwater, however, is of recent origin. Where man made wells did not go deeper than 15 to 20 metres under normal conditions and say about 100 metres in arid zones, today it is possible with powerful rotary drills to tap groundwater resources as deep as 1,000 metres. In California they have some wells 2,000 metres deep. In this way the knowledge in groundwater hydrology which was hidden all these centuries has received a tremendous stimulous and has expanded very considerably in recent decades. Much more pioneering work in this direction is being done and this knowledge is expected to grow even at a faster rate in future.

3. India is perhaps the only country in South-East Asia which has undertaken exploration and assessment of her groundwater resources on a nation-wide scale with the help of the most modern equipment. Although tubewells ranging in depth from 80 to 150 metres and run by electric power had been introduced in the Gangetic alluvium to supplement flow irrigation projects more than 30 years ago, the systematic and scientific treatment of the groundwater problem, its movement and behaviour its quantity and quality and other characteristics has been taken up only recently. An attempt has been made in the following chapters to give a brief description of the investigational methods and techniques, such

as drilling, testing and collecting hydrological data and the equipment used for groundwater exploitation in the hope that it will serve as a useful guide to other countries where similar geohydrological conditions are foreseeable.

4. Exploration and assessment of groundwater resources of a country involve the application of most of the basic science as well as many types of equipment and specialized techniques. The organisation must include trained and experienced groundwater engineers, geologists and hydrologists, besides a crew of drillers and mechanics because the information and data collected by the organisation should afford a firm foundation of knowledge on which to base the conservation, development and utilisation of the hidden sources of water supply for permanent benefit of the country. It should also be remembered that groundwater is a renewable commodity and being almost always in constant circulation underground, it needs collection of information on a recurring basis to study and forestall its movements and behaviour (Table 1).

II. SURFACE INVESTIGATION OF GROUNDWATER

5. Prior to the commencement of drilling operations, it is necessary to select suitable areas from geological and topographical considerations as to the chances of occurence of groundwater in that region. This work involves not only the actual collection and codification of data but also their precise interpretation as to the geohydrological conditions. Prior to assessment of groundwater conditions in different areas, it is necessary to collect data on hydrological, geological, structural and physiographic characteristics of the area as well as the climatic factors such as mean rainfall, and temperature besides already available data and information, howsoever crude, before embarking upon a programme of drilling down to water table or trying to initiate hydrological surveys in any selected area.

6. Lately geophysical methods have been developed for groundwater surveys, which makes the task of preliminary exploration simpler and more reliable. Geophysical exploration is an indirect way to measure certain specific physical properties of the rocks and the confined or unconfined water in them. Experience has shown that differences in these properties can be evaluated in terms of the porosity, water bearing capacity and quality of water contained in various rock types. These methods however, have been used more extensively for the exploration of petroleum and other minerals. Their application to groundwater has been slow since the commercial value of petroleum and minerals overshadows that of water. Several geophysical methods could be listed under this head, but only electrical resistivity and seismic refraction methods have more than limited application to groundwater and they are easily applicable for groundwater investigations.

Geological methods.

7. Geological methods are the simplest and least expensive scientific approach in the evaluation of subsurface water resources. Normally, geologists resort to the collection of information on composition and structure of the rocks exposed on the surface to arrive at optimum magnitude of water yield to be expected from one formation to another. Study of the geomorphological phenomena, like erosional and depositional feature which may afford clue to the extent and regularity of water bearing formation is also essential.

Stratigraphy and geological history of the area may reveal the potentialities of water and depth of drilling in a particular formation. The geological reconnaissance of the region eliminate/unnecessary drilling in non feasible areas. Prima facie based on the geological reconnaissance survey, suitable areas for groundwater exploration can be marked for systematic drilling programme.

Dowsing.

8. Dowsing or water witching is an age old method of locating underground water or streams by the intuition of supernatural powers or by dividing methods. It lacks complete scientific justification and is more of a trade and persons of such show are known as "Water Diviners"; "Paniwala Maharaj" "Radiasthetists" etc. Each one of them has his own specialised approach and instruments. The authenticity of such methods if highly doubtful and the results are more speculation shrouded in mystery. However, this age old method used all over the world in some form or the other, points to the urge of human beings to search for water which is buried deep in the ground. With the dawn of scientific methods and advances made in the study and exploration of groundwater such primitive ways like water divining are slowly losing ground.

III. SUBSURFACE INVESTIGATION OF GROUNDWATER

9. Reliable and comprehensive studies of groundwater and conditions under which it occurs particularly the nature of aquifers, location, thickness, composition permeability, yield and quality can only be made by subsurface examination. Test drilling furnishes information on the condition of the strata below the surface. Logging techniques provide data on the water bearing properties of the formation with reference to the quality of water, size and magnitude of the granular zones, rate of groundwater flow, etc., Evaluation of these factors aid in proper location, development and utilisation of groundwater.

Test Drilling.

10. Small diameter Pilot holes 15 Cms (6") are drilled to ascertain the subsurface geological conditions. These holes later serve as observation holes in measuring hydrological data such as water levels and carrying out pumping tests. The geological strata samples collected from this hole go to form a "Well log" or "Strata Log" or "Lithological Log". Measurement regarding confined or unconfined aquifers can be made from test holes. A drilling time-log from a test hole is a useful supplement for efficient drilling operation during regular drilling. Any type of rig can be used for test hold drilling depending upon the purpose and objective of such test wells.

Resistivity logging.

11. After drilling a test hole or an observation well, the hole is left uncased

for measuring electrical resistivity of the surrounding media and to obtain relative variation in depth. The outcome of such an investigation is an "Electric Log" or "Resistivity log". This log consists usually of a curve or a series of curves termed as "Resistivity curves". These curves are made use of to interpret the lithology of subsurface strata and to decipher the quality of water.

12. Sometimes in old wells, exact location of well casing can also be determined. In an unconsolidated aquifer the resistivity is controlled primarily by the porosity and packing, water content, degree of saturation and temperature. The resistivity of groundwater depends upon the ionic concentration and mobility of salt solution in the water. There is a direct relationship between the temperature and resistivity values. Resistivity logs are useful for locating aquifers, determining bed sequences, correlating aquifers and estimating quality change in groundwater.

Potential logging.

13. This method measures natural electrical potentials found in the various formations. These are also termed as "Self Potentials" or "Spontaneous Potentials", or simply "S.P.". There are two sets of measurements. The one is called positive value i.e. flow from the formation into the well and the other reverse flow called the negative value. These are normally termed as "anomalies", and are interpreted with reference to a base value which might be either of a permeable or impermeable formation of considerable thickness. Therefore, these potential logs indicate relative permeable zones. In areas where there are no sharp contrasts between the permeable zones, potential curves lack relief and are of little value. Usually this logging is carried out along with Resistivity logging and they confirm the subsurface data, obtained during Resistivity Logging Operation.

Other methods.

14. Temperature logging records the vertical variation of temperature in a well by using a resistence thermometer. Ordinarily temperature in a well increases with depth in accordance with the geothermal gradient i.e. roughly 1°C for every 30 metres (100 feet) in depth. Any departure from this may provide information on fluid circulation or geologic conditions in the well.

Caliper logging.

15. Caliper logging is a device to measure the diameter of a hold from the surface to the bottom. Other methods of logging which are used in a very limited way are logs of pH values, to study chemical characteristics of groundwater.

16. Radioactive logging using gamma and neutron rays have wide application in petroleum prospecting to analyse the formations in oil wells. This method is used only in exceptional cases in the water wells for estimating porosity and moisture contents. Tracer techniques are used to estimate groundwater flow and velocity.

IV. METHODS AND TECHNIQUES

17. The aquifers, determined as a result of pilot hole drilling and electrical logging, are taken up for testing for their yield and quality of water. Where the quality of water from all the zones is good, cumulative or combined aquifer tests are carried out. Individual aquifers performance tests involving application of packers etc., are costly and time consuming and are resorted to only where absolutely necessary. The results of these tests indicate the zones worthy of

development and those that are to be sealed off in order to eliminate unacceptable quality of water. Keeping those in view, gravel shrouded test wells are constructed and developed with compressed air. The test wells are then subjected to step drawdown, aquifer performance and recuperation tests using diesel driven turbine pumping sets of suitable specifications. The processes of testing are briefly enumerated below ad seriatum:-

a) As the drilling progresses the samples coming out of the "Tee" pipe are collected in sample catchers for every ten feet or with the change in formation whichever is earlier. The latter fact is noted by periodically collecting the sample in local sieves during the progress of drilling. Portion of this sample is taken in a muslin bag and washed free of mud, dried and stored in sample box, marking the depth it represents. It is from these samples that the initial formation log is compiled.

b) The naked hold with a wall plastered with mud is electrically logged by using a single or double channel electric logging device, known as "Electric Logger". In electric logging, the hole is filled with mud and one electrode is passed in the hole while the other kept on the surface in the mud. The separate curves obtained can be interpreted for resistivity and self potential, to get the relative idea of granular zones and their relative salinity. The electrical log compared with the formation log to get the correct idea of the formations drilled through, and thereby to compile an authentic lithological log for all practical purposes.

c) The granular zones that are likely to be productive are then mechanically analysed by using standard mechanical sieve sets, preferably by using mechanical sieve shaker by taking about 100 gms, of the cleaned granular formation. This gives an idea of the mean size of the formation and its effective porosity. Mean gravel size recommended is of the order of 4 to 6 times that of the formation size. The formation comprising gravel do not therefore need any gravel packing in a water well.

18. In case the formations are too thin to sustain a desired draft, the well is straight away abandoned. If they are adequate in thickness the well is converted into a production well. In all other cases the formations and the doubtful zones amongst them are tested for quality and/or quantity to get an idea of their potentiality by using imported or indigenous packers to effectively seal off the undesired zones. In testing an aquifer the discharge is normally recorded on a V-notch and the water sample collected is submitted to partial analysis. If these tests indicate satisfactory conditions, the bore is converted into a production well.

19. For converting the Pilot hole into a production well it is reamed to the desired size, and the designed housing and casing assembly is lowered. The annular space is gravel shrouded. The well is first developed by compressed air and later by a turbine pump. When the water is sand free it is considered to have been fully developed. On such a well, stepdrawdown and aquifer performance tests are conducted. In the former, the discharge is noted by manometer reading against the RPM of the pump to determine the safe yield of the well at a reasonable drawdown. In the latter test the groundwater parameters are calculated by taking note of the recuperation data as well. A steel tape is generally used to record the depth to water, but an electrical water level recorder is preferred to eliminate human error in the process. Amongst the groundwater parameters, Transmissibility is calculated by using "Theis" formula:

$$T = \frac{264 \times Q}{\Delta S}$$

Where Q = the discharge in U.S. G.P.M. and
Δ S = residual drawdown over one log-cycle

20. The coefficint of transmissibility is denoted as the discharge in cubic feet per minute through each square foot of cross-sectional area under 100 per cent hydraulic gradient. Drawdown is recorded by the difference in pumping and static water levels. Coefficient of permeability is expressed as number of gallons of water per day per square foot of cross-sectional area at 60°F and calculated by dividing 'T' with the thickness of the aquifer tapped.

V. EQUIPMENT

21. On the correct choice of drilling equipment depends the ultimate success of the project. Prior to ordering the correct type of equipment, it is essential to make a close study of the job conditions like geological formation to be drilled, probable depth of drilling, transport problems, etc. For most purposes, diesel driven, trailer-mounted direct rotary mud circulation rig is suitable. Where water for drilling is difficult to obtain, air circulated rotary may be preferred. In sandy areas where it is difficult to transport pneumatic wheeled equipment, caterpillar mounted rigs would be the best choice. In hard bouldery areas, rotary rigs do not operate satisfactorily and rotary-cum-percussion rigs would be a better choice, for drilling such formations. Reverse circulation rigs are meant for production well drilling in alluvial formations; but they are not quite suited for individual formation testing in exploratory work. Greatest economy can be observed by buying rigs of similar types to facilitate interchangeability of spare parts.

22. For rotary drilling work, Tricone rock-roller bits with different surfacing materials are manufactured over a range of sizes to suit different drilling conditions. Use of hole openers with replaceable cutters results in considerable economy. In exploratory work, it is often necessary to take out cores. As such suitable core barrels and core bits must be ordered along with the rig.

23. Formation testing involves use of different types of packers - combination rate-hole, inflatable rubber sleeve, etc. Under certain conditions improvised packers may also have to be employed.

24. The rig units must be supported by a fleet of dependable transport equipment. Heavy duty oil field trucks each equipped with tow-hook, gin pole and winch attachment are useful for a variety of jobs including towing rigs, installation of pumps, etc.

25. Pumps tests are done with the help of air compressors and multiple-stage turbine pumps. The diesel driven compressors should be capable of developing a pressure of at least 150 p.s.i. and delivering 500 c.f.m. of air. Turbine pumps of different sizes and capacities are required to suit varying conditions.

26. In exploratory work slotted tubes of different designs are used depending on the job condition. It is, therefore, essential to equip the Organisation with a casing perforating machine to turn out slotted tubes of required sizes.

27. On the maintenance side, the base workshops should be equipped with tools for carrying out complete overhaul of rigs, vehicles, compressors, etc., and also for dressing bits. Truck-mounted mobile workshops are useful for carrying out jobs in the field.

Geological Equipment

28. The geological equipment required for purposes of groundwater study in any area is of fairly simple nature. A Brunton Compass, a field lens, geological hammer, pen knife, field magnetic and a topo-sheet of the area on the desired scale is all that is required by the field geologist for mapping an area. With these essential equipment, he proceeds to examine the formations where tubewell possibility is to be worked out; and compares them with the geological formations recorded in the standard stratigraphical succession of the country. Normally, hard rock areas which are not likely to contain any granular zones whatsoever, are not considered suitable for tubewells, unless it is ascertained that in such rocks there are likely to be adequate joints, faults and such other zones of weaknesses entombing adequate quantity of water.

29. Once the area has been suggested for exploration by locating suitable sites at reasonable distances, with an idea of getting clear picture of the groundwater behaviour in such area, it is taken up for systematic exploration. At individual site, formations are collected as drilling progresses at 10 ft. interval or with the change of formation. These formations are dried and examined further for their heavy minerals, fossil contents, particularly in case of the granular zones containing them. Study of microfossil in the formations encountered during the course of drilling is a subject by itself, for which, adequate laboratory and library facilities are required. For heavy mineral study the granular zones are subjected to heavy mineral analysis by using first a superpanner and then an isodynamic separator to isolate individual mineral grains. Slides of individual isolated mineral grains are then prepared which are examined in a petrological polarising microscope. Such study helps to locate the source of granular material encountered in the borehole; and a collective study can often provide adequate clue to the recharge area of the investigated basin. Granular formations encountered in the boreholes are also subject to mechanical analysis by using standard sieves to find out the screen size and the effective size of the formation. It must be remembered that the nature and the size of gravel to be shrouded in a well depends upon the nature and the size of the granular zones encountered in the exploratory borehole.

30. A well equipped geological and a petrological laboratory with an addition of a chemical wing is a pre-requisite for any groundwater investigation.

VI. QUALITY TEST OF GROUNDWATER

31. Quality of water is as important as the discharge from a well. The standards of quality of water depend upon the purpose for which it is required. Thus the needs for drinking water, industrial water, irrigational activity, vary widely. Quality criteria is judged by the three principal factors, i.e. chemical, physical and bacteriological.

32. Water to be used for drinking purposes, need not be chemically pure, because lack of dissolved and suspended matter makes it both unpalatable and unhygenic. In fact, it is generally believed that the presence of certain minerals in water is essential to health. Chemically pure water is not found in nature because of the almost universal solvent power of water.

33. The following statement gives a brief outline of the desirable and undesirable matters in water.

DESIRABLE AND UNDESIRABLE MINERAL MATTERS IN WATER

The amounts are stated in parts per million of the ion indicated. They are to be taken as suggestive only.		
Use	Desirable or permissible	Undesirable or objectionable
Domestic, drinking and cooking.	Ca Mg Cl HCO_3 F - - - - 0.01	CO_3 SO_4 Cl Fe F 200 0.5 0.1
Irrigation	Ca Mg 40 20	Na Cl SO_4 CO_3 B 10 100 200 10 0.1
Steam boiler	None	Ca Mg SO_4 HCO_3 Cl 5 5 100 100 100

34. Normally four to five litres of water sample are collected for complete chemical analysis; for partial chemical test about half a litre is enough. The categories of samples required for testing are, drilling water - drilling mud and formation water.

35. The constituents which are normally analysed, in any given water sample, and reported in terms of ppm are ;

SiO_2 Fe Al Mg Cu In Pb Ca Na K PO_4 CO_3 HCO_3 SO_4 Cl

NO_3 B TDS pH $CaCO_3$ Total Iron (fe) Hardship and physical tests are Specific conductance - Temperature - Colour and Turbidity.

36. Certain waters are reported to be toxic due to the presence of certain undesirable constituents such as Boron and excess of chloride.

VII. DESIGN AND CONSTRUCTION OF TUBEWELLS

37. After proving the potentialities of groundwater, by actual drilling and necessary yield tests, the question arises of constructing a tubewell which would give the maximum quantity of water at the minimum pumping cost. Well design usually starts with an analysis and interpretation of aquifer characteristics and gradation of aquifer materials. On this depends the design of the assembly to be lowered and the size of the screen opening. The screens placed opposite the granular zones have to be carefully designed for the size of the slots. These openings or slots are to be determined by mechanical analysis of sample formation. Great care is to be taken in this analysis as screen openings which are too large will let in much sand while openings that are too small will fill up with fine sand and choke the screen. Screen openings are selected on the basis of a certain percentage of the finer particles being passed into the well and removed. This is done by means of pumps and surges and bailers operated in the well casing after the screen is set. This process is called "development" and has its own importance in the future working and life of the well. Optimum well designs frequently require that the screen be surrounded by material having a coarser or more uniform grain size than the natural aquifers. This is particularly necessary in the fine sand formations. This artificial feeding of the coarser materials is known as "gravel pack".

The grading of this gravel or coarse material is based on the grading of the fine sand of the natural formation.

38. The materials used in the well construction must be given due consideration if long life is wanted in the finished wells. The two phenomena which result in the failure of wells and which are beyond the control of well drillers and well users are corrosion and incrustation. Both are due to the chemical constituents of the groundwater which cannot be controlled. For this reason, metals should be used in screens and casings which will resist corrosion and incrustation. Incrustation is directly caused by the upset pressure balances when the well is pumped. This can be removed sometimes successfully by acid treatment. The rate of deposit of incrustation can also be retarded by the reduction in the rate of pumping.

39. When a well in an unconfined formation is pumped, there is lowering of water level in the well as well as in the formation. This lowering around the well is called the "Circle of Influence" and the dip in the groundwater bed is called the "Cone of depression". This is important because it determines the distance between the wells if more than one well is to be sunk in the area to avoid interference between adjacent wells.

40. The choice of pumping equipment should be based on information obtained during and development stages; and the pump should be of the right type and design capable of lifting a greater quantity than is required for permanent extraction. There are many types of pumps in the market and each claiming special characteristics. In shallow wells, suction type of pumps are more suitable. For deep wells, deep borehole pumps or submersible pumps are the best. Their choice is generally governed by the knowledge of the exact forms of the yield depression curves of the well and the seasonal extremes of fluctuations of water levels. It is not unusual to find wells abandoned because they are equipped with wrong types of pumps.

VIII. SEA WATER INTRUSION IN COASTAL AQUIFERS

41. This phenomena is of common occurrence in the coastal regions. Under natural conditions, fresh groundwater is discharged into the ocean. In some instances when there is a decrease in seaward flow, reversal flow of sea water into the fresh water aquifers may occur. This may be caused due to overdraft conditions in coastal aquifers connecting the sea thus resulting in the sea water intrusion. Influence of connate water is another important factor that has to be taken note of in any groundwater exploratory programme. Protecting such occurrence is of utmost importance since the fresh water aquifers become contaminated with salt, thus rendering them useless and it takes several years to flush them out. Sea water intrusion may also develop or be accentuated wherever a direct artifical access exists between sea water and groundwater.

Prevention and control of sea water intrusion

42. Five conventional methods have been suggested for controlling intrusion - (i) Reduction and/or controlling the rate of pumping (ii) Direct recharge (iii) Development of pumping through adjacent to the coast (iv) Maintenance of fresh water ridge above sea level along the coast, and (v) Construction of artificial subsurface barriers.

Detection of seawater intrusion into the groundwater

43. This is determined by the chemical analysis of groundwater sample at the zones of sea water intrusion. Chloride is the dominating constituent in ocean water. On the other hand, bicarbonate is usually the most abundant negative ion in groundwater and occurs only in minor amounts in sea water. The ratio of chloride/bicarbonate is the dominating factor to determine sea water intrusion. The increase of chloride/bicarbonate ratio as well as the total salinity can be seen as the coast is approached.

IX. ARTIFICIAL RECHARGE OF GROUNDWATER

44. Recharge to groundwater is one of the main criteria to ensure continuous and copious supply of water without which the constant depletion of groundwater might cause draught conditions and ultimately all the developmental activities may have to be abandoned.

45. Artificial recharge means augmenting the natural infiltration of precipitation of surface water into groundwater by imposing artificial barriers or by artificially changing the natural conditions. Quite a number of methods are in practice, such as water spreading on surface, recharging through pits, excavation wells and shafts and finally overpumping to induce recharge from surface water bodies. The selection of particular method depends upon the local topography, geology and soil conditions, the amount of water to be charged, ultimate use and climatic conditions.

46. Artificial recharge of groundwater is heavily practised in Sweden, Germany and the Netherlands and to a limited extent in France, Great Britain and Spain. Infiltration basins are integral parts of many Swedish Municipal Water Supply systems. Most are located in glacial eskers which are long narrow alluvial ridges deposited during the last glacial era. In Germany, artificial recharge is widely practised where basins and ditches and more recently wells have been utilised. In India, the method of recharging groundwater is still in embryonic condition.

TABLE 1

EXPLORATORY TUBEWELLS ORGANISATION SET UP

N.B. Pump installation crews headed by Pump Foremen are also provided in the division.

1515 E - Nov.1962 - 1,600